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16. Abstract

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Abstract

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1.0 INTRODUCTION

Kansas lies in the center of the Great Plains Province of the United States. This is an area of few permanent natural lakes. As a consequence, virtually all of the standing fresh water resources in the state result from the construction of artificial reservoirs. These include 20 federal reservoirs, 43 smaller state lakes, 24 municipal lakes greater than 50 acres in area, numerous other smaller lakes plus thousands of privately owned farm ponds. These lakes provide recreation, flood control, irrigation, plus stock and domestic water supplies. Timely low-cost water quality information gathered from these lakes and supplied to their governing agencies could aid in the management of the state's fresh water resources. A number of state and federal agencies in Kansas have expressed the need for repetitive water quality data such as suspended solids, dissolved solids, chlorophyll, and the algal nutrients.

Millions of dollars are spent annually by sport fishermen in Kansas. To help insure continued growth and good health for the sport fishing industry, the Forestry, Fish and Game Commission is interested in determining the effect of water environment on fish spawning and subsequent fish population. A knowledge of suspended load distribution in the lakes would allow better fish management. Suspended load maps over a period of time would help to identify the best spawning areas within a reservoir and also would identify source points of undesirable high suspended load.

The Kansas State Health Department (KSHD) is concerned about the unpredictable occurrences of feedlot waste coming in contact with some of the city lakes used for drinking water. The KSHD is also concerned with chlorophyll and dissolved solids in the city lakes. The federal guideline of 500 PPM maximum allowable dissolved solids is often exceeded in the state of Kansas.

Temporal data on sediment load and source point location would allow better estimates of reservoir lifetime. Unusually high increases in sediment load/algal nutrients might permit timely identification of poor cultivation/fertilization practice upstream.

Satellite-borne remote sensors have the capabilities of providing repetitive coverage over wide areas. However, their ability to provide water quality information must be determined. A study was recently completed in Kansas in which the LANDSAT I sensors were evaluated to determine their ability to monitor the water quality of selected reservoirs in the state [Yarger and McCauley, 1974]. It is

likewise the objective of this study to establish correlations between SKYLAB EREP data and water quality parameters of Kansas reservoirs. SKYLAB sensor products used in this investigation are S190A and B photographs and S192 imagery and tapes (S191 data had been requested however none were recorded over our study areas). Concurrent with EREP data recording, lakes being imaged were sampled at a number of prearranged locations. Samples were then analyzed for concentrations of total solids, suspended solids and their heat stable components. The concentrations of various dissolved ions were also measured. Ground truth data was then compared with EREP data to determine those water parameters that were significantly affecting the appearance of the reservoirs on SKYLAB imagery.

2.0 GROUND TRUTH ACQUISITION

Of the twenty large federal reservoirs in Kansas, it was initially planned to concentrate on two lakes in Northeastern Kansas, Perry and Tuttle Creek. These are the same two lakes which were intensively studied during the earlier referenced Landsat I investigation. Perry and Tuttle Creek are two of the largest reservoirs in the state having multipurpose pool areas of 12,200 and 15,830 acres respectively and play major roles in controlling flooding in the lower Kansas River basin. Numerous potential EREP passes were scheduled which would have covered one or both of these lakes during the three manned SKYLAB missions. However, EREP data was recorded on only one of these passes, occuring during the SKYLAB 4 mission on January 11, 1974. On this day Perry and Tuttle Creek reservoirs and virtually every other lake in the state was completely frozen over and snow covered. As a result, only one EREP data pass over Kansas exists for which supporting ground truth was gathered. This occurred during the SKYLAB 3 mission on September 18, 1973 over an alternate test site in Southeastern Kansas along track 58. Ground crews sampled four lakes along or near the ground track of this pass: Redmond, Toronto, Fall River and Elk City. Redmond was beyond the coverage of the Skylab sensors. However the other three lakes were covered by S190A and B photography, and Elk City was imaged by the S192 scanners. Due to the distance between our base of operation and the "last minute" secondary test site, we were unable to obtain the full suite of ground truth measurements originally planned. The most significant measurements not taken were chlorophyll content (due to lack of cooled water samples) and turbidimeter measurements. The planned aircraft coverage with our airplane was not obtained because of a landing gear malfunction the previous day. The three lakes covered are shown in Fig. 1 as well as the approximate ground trace of track 58.

The three reservoirs studied are located on the eastern slope of the Flint Hills in the upper portion of the Verdigris River Basin. Toronto reservoir is located on the Verdigris River itself. Fall River and Elk City reservoirs impound the Fall and Elk rivers respectively which are tributaries to the Verdigris. The water sheds of these lakes lie in the Flint Hills and the Chautauqua Hills of Southeastern Kansas which are underlain by Permian and Upper Pennsylvanian rocks, mostly limestones and shales, but with some Pennsylvanian sandstones in the Chautauqua Hills. This region is used primarily for grazing land with large areas of virgin tallgrass prairie preserved in the Flint Hills and open oak woodlands with interspersed prairie in the Chautauqua Hills.

The three lakes are small when compared to the other federal reservoirs in the state. Their sizes at multipurpose* pool levels range from 2,450 acres for Fall River to 2,800 acres for Toronto to 3,500 acres for Elk City. The lakes are also shallow when compared to the larger lakes. Elk City is the deepest being about 45 feet deep near the dam; the other two lakes are about 25 to 30 feet deep near the dam. Since they are artificial reservoirs the depths of these lakes decrease gradually upstream to the point where the lake merges with the original stream bed.

During the first part of September 1973 prior to the EREP mission of the 18th, a total of nearly six inches of rain had fallen in the watersheds of the three lakes sampled. The last major period of precipitation occurred on September 13 when amounts of 1.00, 1.48 and 2.52 inches of rain were recorded at the weather stations at Elk City, Toronto and Fall River dams respectively. Smaller amounts were also recorded on September 17. At the time of sampling, the three lakes were slightly above their multipurpose pool levels.

The reservoirs were sampled within two hours of the time of actual SKYLAB overflight. Samples were collected just below the surface of the water. Ten samples were collected from Toronto and Elk City reservoirs and six were collected from Fall River according to the sampling schemes shown in Figure 2. The samples were then analyzed by the Geochemistry Section of the Kansas Geological Survey. The concentrations of suspended and dissolved solids in the samples were determined using normal evaporation plus gravimetric procedures. Dissolved solids are defined as material surviving a 0.45 micron filter. The inorganic (heat stable)

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* "Multipurpose" pool level is the pool level best suited to the combined lake uses of recreation, flood control and fish and wildlife management.

fraction of suspended and dissolved solids is defined as material that survives 1 hour at 600°C. Bicarbonate, carbonate and total alkalinity ($CaCO_3$) concentrations were determined by pH titration, calcium and magnesium by atomic absorption, potassium and sodium by flame analysis, sulfate by gravimetric methods and chloride by specific ion electrode means. The results of these analyses are shown in tables 1, 2, and 3.

Examination of the results of chemical analysis reveals fairly uniform concentrations of the various parameters within each of the lakes. This is especially true of Elk City, in which total solids variation is only 18 ppm. Fall River also shows uniform character especially with regard to suspended solids which vary by only 6 ppm. In addition, the numerous ionic concentrations measured vary only slightly within all the lakes. These conditions differ from those observed in Tuttle Creek and Perry Reservoirs. These two lakes often displayed a wide variance in the amount of dissolved and suspended solids, with the concentrations of both increasing towards the upper end of each reservoir. The fact that the three lakes in southeastern Kansas are more uniform across their surfaces than Perry and Tuttle Creek indicates that they are better mixed. A number of factors may account for this. First of all, the Southeastern Kansas lakes are much smaller and water entering the upper ends of these lakes requires less time to reach the dam. Also, these lakes are shallower than Tuttle Creek and Perry, thus they are more affected by winds. Finally, it had been five days since the last heavy precipitation in Southeastern Kansas, enough time for this influx of water and its load to diffuse throughout the lakes.

The suspended portion of the total solids ranges from 13% for Fall River to 14% for Elk City to 31% for Toronto. The inorganic component of the suspended material varies from 82% for Fall River, to 85% for Elk City to 80% for Toronto. The inorganic component of total solids ranges from 68% for Fall River to about 80% for both Toronto and Elk City. Bicarbonate makes up the bulk of the dissolved solids in these three lakes thus classifying them as carbonate waters.

3.0 DATA ACQUISITION AND ANALYSIS

For the EREP pass over Kansas of September 18, 1973 along track 58, imagery was obtained from the sensors S-190A, S-190B and S-192 aboard SKYLAB.

S-190A is a six channel camera system with high precision F/2.8, six inch focal length lenses that provide an 88 nautical mile field of view from the 234 nautical mile

orbit altitude. The spectral windows for the first four bands are shown at the bottom of figure 3. The other two band windows, not shown in figure 3, are 0.5 to 0.88 μm and 0.4 to 0.7 μm. We analyzed second generation 70 mm positive transparencies for bands 1 through 4. The film used by NASA in bands 1 and 2 was PAN X B&W (SO-022) and in bands 3 and 4 was IR B&W (EK-2424). We also received 4x enlargements of S190A bands 1 through 4. Sensitometric data relating enlargements to originals was unavailable.

S-190B, called Earth Terrain Camera, is equipped with an F/4 lens with 18 inch focal length which provides ground coverage of 59 nautical miles square from orbit altitude. We obtained from NASA a five inch positive transparency, presumably second generation, from the single channel, 0.4 to 0.7 μm, high resolution camera which used aerial color film (SO-242).

S-192 is a multispectral camera that optically scans successive contiguous lines across flight path and records simultaneously, in thirteen discrete spectral intervals, energy reflected and emitted by the earth. The first ten channel windows are shown in figure 3. Not shown are band 11 (1.55 - 1.75 μm), band 12 (2.10 -2.35 μm) and thermal band 13 (10.2 - 12.5 μm). Computer Compatable Tape (CCT) was obtained from NASA for bands 1 through 7, 11 and 13.

The other information in figure 3 is shown primarily for the reader's orientation. Note that the first three bands of S190A match the first three ERTS MSS bands, whereas the S-192 bands do not match. Comparison of SKYLAB sensor results with LANDSAT MSS results will be made later in the text. The SKYLAB sensors primarily measure energy reflected from the earth, modified somewhat by atmosphere attenuation. The earth, at ground level, is illuminated by an admixture of sunlight and skylight (lower graph in figure 3) depending on atmospheric conditions. The SKYLAB sensors see a substantially larger portion of the electromagnetic spectrum than seen by the human eye (middle graph in figure 3). Light penetration in water varies with wavelength (upper graph, figure 3) and as will be discussed later, is an important consideration when choosing appropriate bands for water quality detection.

3.1 S-190A and S-190B Analysis

The S-190A and S-190B positive transparencies were first analyzed with the IDECS (Image Discrimination, Enhancement and Combination System) at the University of Kansas Center for Research, Inc. IDECS is an analog-digital image processing system. A vidicon scanner was used as the input device (flying spot scanners are also available as input device). Many processing features are available to perform

enhancement, discrimination and other manipulations of input data. IDECS is interfaced to a digital storage disc and a PDP15/20 computer. The disc enables storage of binary images selected from the input images, and subsequent display in color or black-and-white. Logical operations may be performed on the stored image and displayed in real time.

Visual inspection of the reservoirs contained in the S-190A and B imagery detected tonal variations between lakes but not within a particular lake. In general, Toronto Reservoir appeared to have a brighter appearance than the other two lakes; however, none of the lakes displayed recognizable turbidity patterns. Analysis with IDECS using density-to-hue conversion uncovered some variations on both S-190A and B photos of Elk City Reservoirs. Two regions are delineated; a lower density region in the upper part of the lake and a higher density region elsehwere. Although suspended solids measurements of the Elk City samples do not show much variation, higher concentrations are found in the lower density variations across the surfaces of the other two lakes.

IDECS provides only qualitative information concerning film density variation and is not as sensitive as a densitometer. The four black and white S190A products (4x enlarged) were analyzed quantitively with a Macbeth EP1000 macrodensitometer. The bands analyzed were 0.5-0.6, green (roll 48); 0.6-0.7, red (roll 47); 0.7-0.8, first infrared (roll 43); and 0.8-0.9, second infrared (roll 44). The aperture size used was 1 mm.

Five locations were selected on Fall River and Toronto Reservoirs, and four from Elk City. Each density measurement was centered as nearly as possible over one or more ground truth sampling station. Sample site locations were identified on a map using large shoreline features (e.g., coves, streams, large man-made structures, etc.). Aided by a magnifier focused on the aperture of the densitometer, the shoreline features were used to correctly position the aperture on the film. Granularity studies on S-190A original film (Sensor Performance Report, Vol. I, MSC-05528), which is presumably similar to the film used for the 4x enlargements, indicate that large aperture density measurement error due to granularity will not exceed 0.02. Attempts were then made to relate film density to corresponding water quality parameters. Previous experience in working with LANDSAT imagery has shown that suspended solids dominate the appearance of Kansas reservoirs in satellite imagery in the visible and near-infrared region.

In Figure 4, density is plotted against suspended solids for all three lakes and for all four bands of black and white photography. The sample stations show a range in suspended solids from about 25 ppm to nearly 90 ppm. Based

on extensive sampling of Kansas reservoirs over the last 2 years, these figures represent relatively clear water. These measurements substantiate the visual and IDECS analyses of the photos which failed to detect major tonal variations within any of the lakes. Some variation in tone does exist however, and this is especially evident in the red and green bands. In general, both band densitites show a correlation with suspended solids that decreases with increasing concentrations. The red band to some extent and particularly the green band density levels for Elk City Reservoir are low, indicating that the 4x enlargements were probably made without strict photometric control.

The infrared film densities decrease slightly with higher amounts of suspended solids. This smaller degree of sensitivity to concentrations of suspended material would be anticipated due to the greater amount of absorption of infrared energy by water.

Experience with LANDSAT imagery [Yarger & McCauley, 1974] indicates that sun angle dependence and atmospheric effects on reflected radiance are substantially suppressed by band ratioing (see Appendix A for more discussion on this).

Since sensitometric data was unavailable for the 4x enlarged S190A bands, it was not possible to calculate absolute radiance levels from density measurements. However, radiance ratio values were approximated in the following way. For a positive transparency, density is linearly related to log(exposure), over most of the dynamic range of the film, by the equation:

$$D = D^m - \gamma \log(\alpha E)$$

where D = density of transparency

D^m = maximum density (inertia point)

γ = characteristic of film (normally has value close to unity)

E = radiance detected by satellite sensor

α = constant relating radiance to exposure and depends on attenuation through filter and lens system of camera and by f-stop and exposure time. It also depends on the transfer characteristics relating film to the original.

Rewriting above equation:

$$- D + D^m - \gamma \log\alpha = \gamma \log E$$

assume $\gamma \simeq 1$, then

$$E \simeq 10^{-D} \cdot 10^{D^m - \log\alpha}$$

The radiance ratio between two bands can now be written:

$$\frac{Ei}{Ej} \simeq k \frac{10^{-Di}}{10^{-Dj}}$$

where k is a constant determined by the parameters D_i^m, D_j^m, α_i and α_j previously defined.

From LANDSAT data we expect the red to green ratio to be linear for suspended loads less than 80 ppm. The numerical value of the constant K, or slope, is not required for testing linearity of the SKYLAB S-190A red/green ratio. The red to green band ratio is shown in figure 5 (k is arbitrarily set = 1 in this figure) and exhibits a good linear dependence on suspended solids with RMS residual of 6 ppm. A similar plot is shown in figure 6 in which comparable LANDSAT-I data is plotted. MSS 5 (Red) over MSS 4 (Green) is equivalent to the red to green S190A ratios. Figure 6 represents substantially more data collected during a year of LANDSAT imaging under varying conditions of illumination and sky conditions and over a wide range of suspended solids concentrations. The SKYLAB data (figure 5) compares favorably to the LANDSAT data (figure 6) in the region 0-80 ppm. Beyond 80 ppm the LANDSAT MSS red/green ratio flattens out. We would expect the Skylab S-190A red/green ratio to also flatten out, but the relatively clear water sampled does not permit confirmation of this. The highest two points in figure 5 do, perhaps, indicate a similar flattening.

To shed further light on this characteristic saturation in the green and red bands, a summary of LANDSAT results for MSS4 through MSS7 follows [Yarger and McCauley, 1974]. Band 4 is linearly correlated with suspended solids $\lesssim$ 50 ppm, but flattens out beyond $\sim$ 50 ppm. At 50 ppm the MSS digital levels are approximately one-third the maximum possible value, so this "turnover" is not due to detector saturation. This is also true for the S-190A sensor. There are numerous other targets, away from the reservoir, in the same scene with brighter return (or lower density). Green light penetrates the water column more than the other bands, but as a consequence encounters at 50 ppm, enough scattering material for 100% cross section, or maximum scattering. Band 5 is correlated with somewhat higher suspended solids, $\lesssim$ 80 ppm, but its response to suspended load is quite similar to band 4. Bands 6 and 7 are correlated, although not linearly, with suspended solids up to at least 900 ppm. Although bands 4 and 5 are better correlated for relatively clear water, bands 6 and 7 are the only useful bands for suspended

loads $\geq$ 80 ppm. This is due to the fact that near infrared does not penetrate the water enough for maximum scattering, or saturation to occur. On the other hand, when using bands 6 and 7 for measurement of suspended load it must be remembered that only the first few centimeters of water below the surface are being "sampled" by the near infrared radiation.

The four 70 mm black and white S190A products were also analyzed quantitively with a macrodensitometer. Measurements were made on 70 mm transparencies using a 0.4 mm aperture. Receipt of step-tablets from the Photographic Technology Division of the Johnson Space Center allowed cross-calibration of our densitometer with theirs. Due to the small size of the reservoirs being investigated on 70 mm film, only one density measurement was made for each lake photo. Two of the lakes were well mixed, at time of sampling, resulting in a narrow range of values for the water quality parameters. The suspended load in Toronto Reservoir had a moderate range of 50 ppm. In addition, the value ranges of the major water quality parameters such as suspended solids and dissolved solids within individual lakes are mutually exclusive. Spot density measurements of the lakes taken from 4x enlarged transparencies reveal little density variation within each lake. Thus a lack of multiple density readings over the lakes is not a serious loss of data or control.

Figure 7 is a plot of density versus suspended solids for the three lakes on all four bands of black and white S-190A photography. Points for each lake represent the average value of suspended solids for the samples collected. The densities in all four bands of photography decrease with increasing concentrations of suspended solids. These results from 70 mm film are superior to those derived from the 4x enlargements shown in figure 4. Elk City no longer has anamolously low densitites and the two infrared bands are better correlated.

The densities in figure 7 were converted to radiometric units following the procedures and data in the SL/3 Sensitometric Data Package (report number JL1-2503, section 6). The apparent target radiance in each band was determined by averaging over the film spectral sensitivity in each band. These radiometric units were then plotted versus suspended solids (figure 8). All four bands exhibit good positive correlation with suspended solids. These results are similar to those obtained using LANDSAT digital tape values recorded over Perry and Tuttle Creek reservoirs to the north. A more complete comparison of Skylab and LANDSAT data is reserved for a later section. S-190A radiances were ratioed and plotted against suspended solids. Two ratios were calculated. Red to green and the first infrared to green and are shown in figure 9. Ratioing for this single S-190A pass does not appear to improve the correlation

already established in figure 8. However, the slopes in figure 8 depend on sun angle whereas the slopes in figure 9 are sun angle independent.

The heat stable suspended solids in tables 1, 2 and 3 represent the inorganic component of the total suspended solids. The difference between total and heat stable suspended solids represents the organic component of the suspended solids. The SKYLAB bands were unable to discriminate between inorganic and organic suspended load. One reason for this is the inorganic (and organic) fraction is highly correlated with total suspended load (see figure 10 for an example).

It is clear that the radiance levels detected by the SKYLAB sensors are primarily influenced by suspended load. To make a fair test of the SKYLAB sensors' ability to detect other water quality parameters it must first be established that the parameter in question is largely uncorrelated with suspended load. Dissolved solids appear to satisfy this condition (figure 11) so that their influence, if any, on radiance levels should be detectable when plotted as shown in figure 12. No correlation is evident which indicates that dissolved solids up to 250 ppm have little or no influence on reflectance levels. Calcium and bicarbonate concentration also show no obvious correlation with S-190A bands (not shown). This is no surprise since these ions make up the bulk of the dissolved solids. Similarily, none of the smaller fractions of ionic concentration were correlated with radiance levels.

3.2 S-192 Analysis

S-192 multispectral scanner data was analyzed in the form of computer compatible tapes (CCT's). The nine bands analyzed were bands 1 through 7, 11 and 13. Because of the narrow field of view of this sensor only Elk City, of the three lakes sampled, was imaged. Thus, discussion of S-192 results will center on this lake only.

Digital level maps from the CCT's for Elk City reservoir were generated for each of the nine bands received. Nine pixels were selected which were centered over each sampling station on the lake. The counts were averaged for each station for each of the nine bands and were then converted to absolute radiance levels using the calibration coefficients on the CCT header record.

In figure 13, S-192 radiance is plotted against suspended solids. Although there is considerable scattering of the radiance values, they generally increase with increasing amounts of suspended solids. Band 11, in the infrared, shows very little response to suspended solids as does band 13 which is not plotted. Bands 1, 2 and 6 show a fairly good response.

Various S-192 band ratios were examined. The most effective ones are shown in figure 14. The band 3/band 4 ratio dramatically improves the point scatter present in the individual bands before ratioing (see figure 14) and is better correlated with suspended load. The original point scatter may be due to the presence of a few low small cumulus clouds, or their shadows, over Elk City Reservoir. As described in Appendix A, ratioing would tend to cancel variations in atmospheric transmittance caused by the clouds. The IR/Green ratio also exhibits a fairly good linear correlation with suspended load.

Since the other measured water quality parameters in the one reservoir, Elk City, covered by S-192 had little or no variation, it was not feasible to look for correlation with reflectance levels as was done for S190A.

4.0 Comparison of SKYLAB to LANDSAT

S-190A and S-192 data were compared with LANDSAT data to determine the amount of agreement between the three sensors and to gain some idea of the relative usefulness of each for the study of water quality. All bandwidths for LANDSAT and SKYLAB are shown in figure 3. The first three black and white bands of S-190A photography cover the same spectral regions as the first three LANDSAT bands. The S192 bands do not correspond as closely to the LANDSAT BANDS. An average of S-192 bands 3 and 4 was used to compare with LANDSAT MSS4 imagery and S-192 bands 5 and 6 were selected for comparison with LANDSAT MSS5 and MSS6 respectively. LANDSAT data used for comparison was selected from those LANDSAT passes over Perry and Tuttle Creek that occurred at approximately the same time of day and year as the SKYLAB overflight; that is, 11 am during late August to early October 1972 and 1973. Thus, the sun angles for the LANDSAT and SKYLAB data are approximately the same, 40°-54°. The look angles for LANDSAT and SKYLAB were always between 78° and 90°. The LANDSAT data represents radiance levels for about 60 water samples from 7 passes.

Radiance values for S-190A, S-192 and LANDSAT are plotted against suspended solids in figure 15. The agreement between S-190A and LANDSAT in the three bands green, red, and IR is quite good. The agreement between S-192 and LANDSAT radiance levels is poor in the green band, fair in the red and good in the IR. The poor agreement in the green bands may be due to the fact that the band widths for the S-192 green and the LANDSAT green are not an exact match.

SKYLAB band ratios are plotted against suspended solids in figure 16. All ratios, except perhaps S-192 red/green, are consistent with linear fits to LANDSAT ratios.

The small amount of data available from the S-190A and S-192 sensors aboard SKYLAB is in general quantitatively consistent with water reflectance levels measured by the LANDSAT MSS sensor. It appears that S-190A is superior to S-192 for the purpose of predicting suspended solids in water. However, more data is needed to confirm this single pass result. Statistical analysis of the small SKYLAB data set would not yield reliable results. Comparison of SKYLAB data to much larger LANDSAT data set indicates that SKYLAB Band ratios would probably yield results comparable to LANDSAT results. Therefore it is estimated that the predictive accuracy of the SKYLAB sensors S-192 and S-190A in the range 0 to 100 ppm suspended solids is $\pm$ 12 ppm for the red/green ratio and $\pm$ 20 ppm for the IR/green ratio. These uncertainties represent a 67% confidence level and correspond to the one standard deviation linear swaths shown in figure 16. A 6 ppm RMS residual was obtained between suspended load and the red/green ratios derived from 4x S-190A enlargements. However, as discussed earlier in the text, a dubious photometric control on these enlargements may mean that the low residual was a lucky occurrence.

5.0 CONCLUSION

Analysis of S-190A, S-190B and S-192 data from one pass over 3 Southeastern Kansas reservoirs indicates that these sensors are useful for quantitative determination of suspended load. Several of the band ratio combinations from S-190A and S-192 are linearly correlated with supended load in the region 0-100 ppm. Comparison of the relatively small amount of SKYLAB data to a much larger LANDSAT data set indicates that the SKYLAB sensors are probably as effective as the LANDSAT MSS in quantitative determination of suspended load. The estimated 67% confidence level predictive accuracy for these sensors is $\pm$ 12 ppm over the range 0 to 100 ppm. The S-190B photography is of very high quality, although it has limited usefulness for quantitative measurement. It is very useful for visual "first look" identification of water bodies and turbidity patterns within.

Other water quality parameters such as dissolved solids and major ionic concentrations show no correlation with radiance levels detected by SKYLAB sensors. This result is consistent with LANDSAT results.

Appendix A - Sun Angle and Atmospheric Effects

After Vincent (1972), an arbitrary band ratio R_{ij} can be approximately expressed as follows:

$$R_{ij} = \frac{L_i}{L_j} = \frac{E_i\tau_i\rho_i/\pi + P_i}{E_j\tau_j\rho_j/\pi + P_j}$$

where

L_k = radiance in band k at satellite orbit altitude

E_k = irradiance of sun in band k impinging on target

τ_k = atmospheric transmittance in band k

ρ_k = reflectance of target in band k

P_k = path radiance in band k (reflectance from atmospheric scattering)

k = band number (e.g. k = 1,2, 3, or 4 for S190A)

If we assume that path radiance, P_k, is substantially less than the direct radiance, $E_k\tau_k\rho_k/\pi$, i.e.

$$P_k \ll E_k\tau_k\rho_k/\pi$$

then

$$R_{ij} = \left(\frac{E_i\tau_i}{E_j\tau_j}\right)\frac{\rho_i}{\rho_j}$$

The environmental factors, E_k and τ_k that depend on sun angle (time of year) and atmospheric scattering, are suppressed by ratioing. The only term that is free to vary from frame to frame or from one part of the scene to another is the ratioed target reflectance term ρ_i/ρ_j. A test of this ratioing hypothesis, using LANDSAT data, is shown in figures A-1 and A-2. The radiance levels from the concrete dam at Tuttle Creek Reservoir, a target with constant spectral reflectance, show a strong sun angle dependence in all MSS bands (figure A-1). The sun angle dependence is suppressed by plotting band ratios instead of absolute levels (figure A-2). The three other possible ratios, not plotted in figure A-2, also show a flat response to change in sun angle. Ratioing essentially removes the effect of unequal illuminating intensities and atmospheric conditions from one LANDSAT pass to the next. The assumption that path radiance is not an important factor appears to be valid. To test this, dark object subtraction was done on each band before ratioing. This did not improve the "flatness" of the ratio curves in figure A-2. Dark object subtraction is the radiance level from the target detected by LANDSAT minus the radiance level from the darkest object in the scene detected

by LANDSAT. The darkest object in the scene is presumably in a shadow with no direct illumination from the sun. Consequently, the radiance from the darkest object at satelite altitude should represent path radiance only.

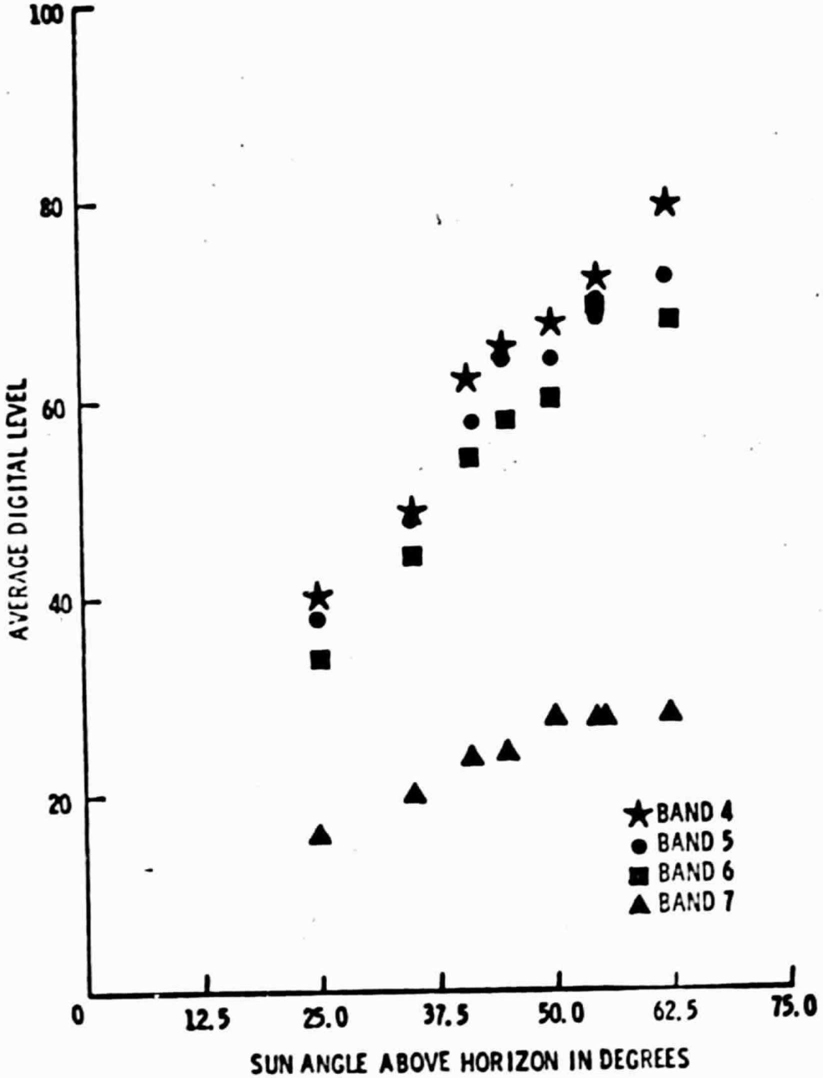

FIGURE A-1. MSS DIGITAL LEVELS FROM CCT VS. SUN ANGLE FOR TUTTLE CREEK CONCRETE DAM.

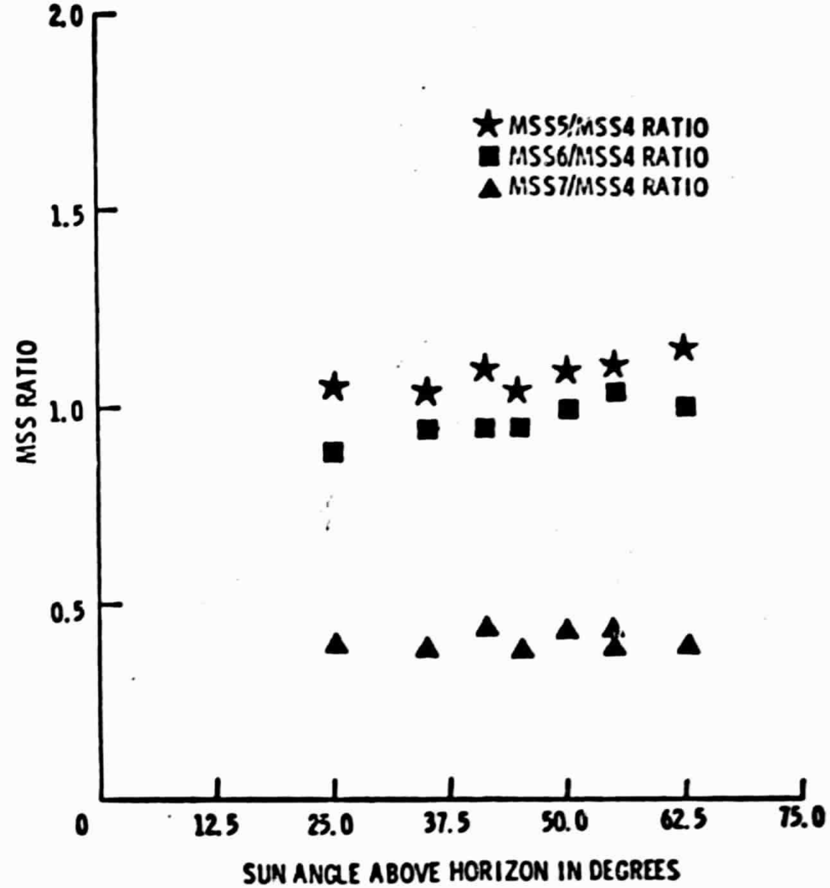

FIGURE A-2. MSS BAND RATIOS FROM CCT VS. SUN ANGLE FOR TUTTLE CREEK CONCRETE DAM.

REFERENCES

Yarger, Harold L. and James R. McCauley, "Monitoring Fresh Water Resources," Type III Final Report, March 24, 1974. Available from NTIS.

Vincent, Robert K., (1972), "An ERTS Multispectral Scanner Experiment for Mapping Iron Compounds": Proceedings of the Eight International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, Oct. 2-6, pp. 1239-1243.

TABLE 1

TORONTO SAMPLE ANALYSES

SAMPLE SITES

CONC. (PPM)	1	2	3	4	5	6	7	8	9	10
Bicarbonate	113.0	112.0	114.0	115.0	102.0	97.0	115.0	106.0	96.0	106.0
Carbonate	0	0	0	0	0	0	0	0	0	0
Calcium	40.1	39.7	41.3	41.3	38.0	41.3	36.7	38.7	37.4	32.6
Magnesium	8.51	8.66	4.46	4.49	4.28	4.6	4.04	4.31	4.08	3.57
Potassium	2.9	3.0	3.1	3.2	3.4	3.6	3.2	3.4	3.5	3.5
Sodium	18.3	17.5	18.3	18.4	16.6	18.6	15.3	16.6	16.1	12.7
Sulfate	23.1	22.6	21.1	22.4	14.2	22.1	16.1	20.7	25.5	21.0
Chloride	32.7	34.8	35.1	33.3	30.0	36.1	29.9	33.2	20.1	20.0
Total Solids	237.0	269.0	210.0	210.0	235.0	251.0	265.0	248.0	247.0	243.0
Total Heat Stable Solids	203.0	195.0	195.0	197.0	196.0	190.4	195.0	194.0	199.0	212.0
Susp. Solids	58.0	63.0	63.0	62.0	85.0	66.0	89.0	72.0	88.0	107.00
Susp. Heat Stable Solids	51.0	56.0	55.0	54.0	71.0	57.0	77.0	64.0	79.0	93.0

TABLE 2

FALL RIVER SAMPLE ANALYSES

	SAMPLE SITES					
CONC. (PPM)	1	2	3	4	5	6
Bicarbonate	140.4	139.0	139.0	139.0	138.0	140.0
Carbonate	0	0	0	0	0	0
Calcium	47.5	47.6	47.6	46.8	46.6	46.6
Magnesium	11.8	12.0	12.1	12.0	11.7	12.2
Potassium	4.3	4.0	4.3	4.3	4.1	4.0
Sodium	22.8	23.5	24.0	21.5	20.0	20.0
Sulfate	22.3	24.7	23.5	23.5	23.2	23.5
Chloride	45.4	43.2	47.7	46.0	44.2	44.1
Total Solids	287.0	296.0	291.0	301.0	333.0	291.0
Total Heat Stable Solids	189.0	184.0	194.0	197.0	235.0	221.0
Susp. Solids	36.0	36.0	41.0	44.0	42.0	37.0
Susp. Heat Stable Solids	24.0	30.0	34.0	36.0	34.0	36.0

TABLE 3
ELK CITY SAMPLE ANALYSES

	SAMPLE SITES									
CONC. (PPM)	1	2	3	4	5	6	7	8	9	10
Bicarbonate	140.0	139.0	140.0	137.0	140.0	139.0	140.0	136.0	139.0	140.0
Carbonate	0	4.0	4.0	0	0	4.0	0	2.0	1.0	4.0
Calcium	50.9	51.1	51.1	52.2	51.5	51.4	51.3	51.5	51.3	51.4
Magnesium	8.64	8.55	8.79	9.15	8.74	8.72	8.79	8.7	9.19	9.32
Potassium	4.5	4.7	4.5	4.9	5.1	4.8	4.8	4.9	4.8	4.7
Sodium	14.3	14.0	14.0	14.4	14.6	13.8	13.9	13.6	13.5	13.5
Sulfate	24.2	24.8	25.5	24.2	26.6	23.2	25.8	24.2	27.0	25.5
Chloride	22.3	25.7	24.2	25.8	27.3	25.3	23.3	24.4	24.4	23.9
Total Solids	207.0	210.0	211.0	225.0	223.0	212.0	223.0	222.0	218.0	219.0
Total Heat Stable Solids	162.0	167.0	160.0	178.0	187.0	166.0	172.0	173.0	185.0	180.0
Susp. Solids	31.0	19.0	28.0	44.0	31.0	31.0	31.0	29.0	30.0	25.0
Susp. Heat Stable Solids	27.0	15.0	23.7	38.0	27.0	24.0	27.0	25.0	26.0	22.0

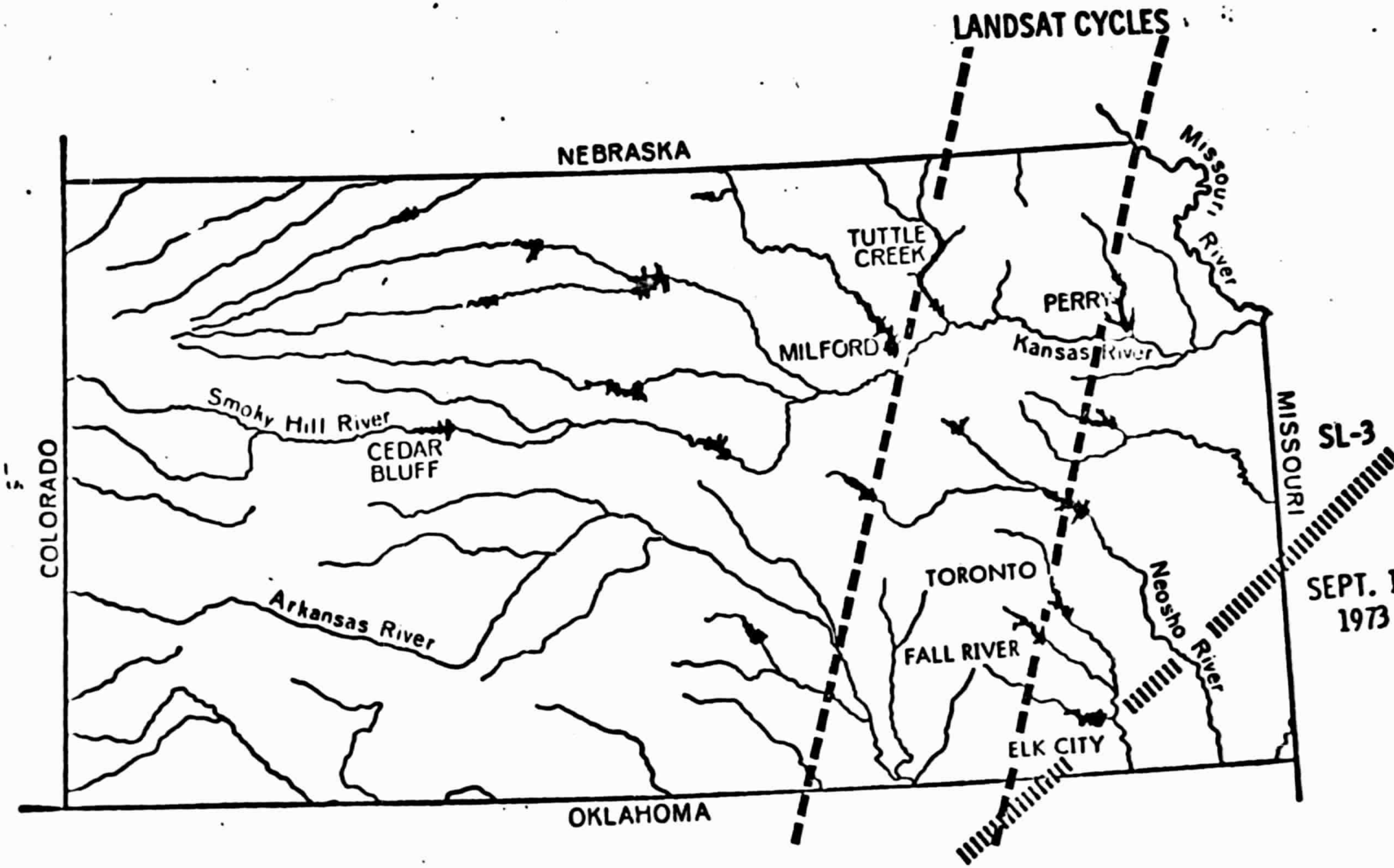

FIGURE 1. LANDSAT AND SKYLAB 3 GROUND TRACKS IN KANSAS.

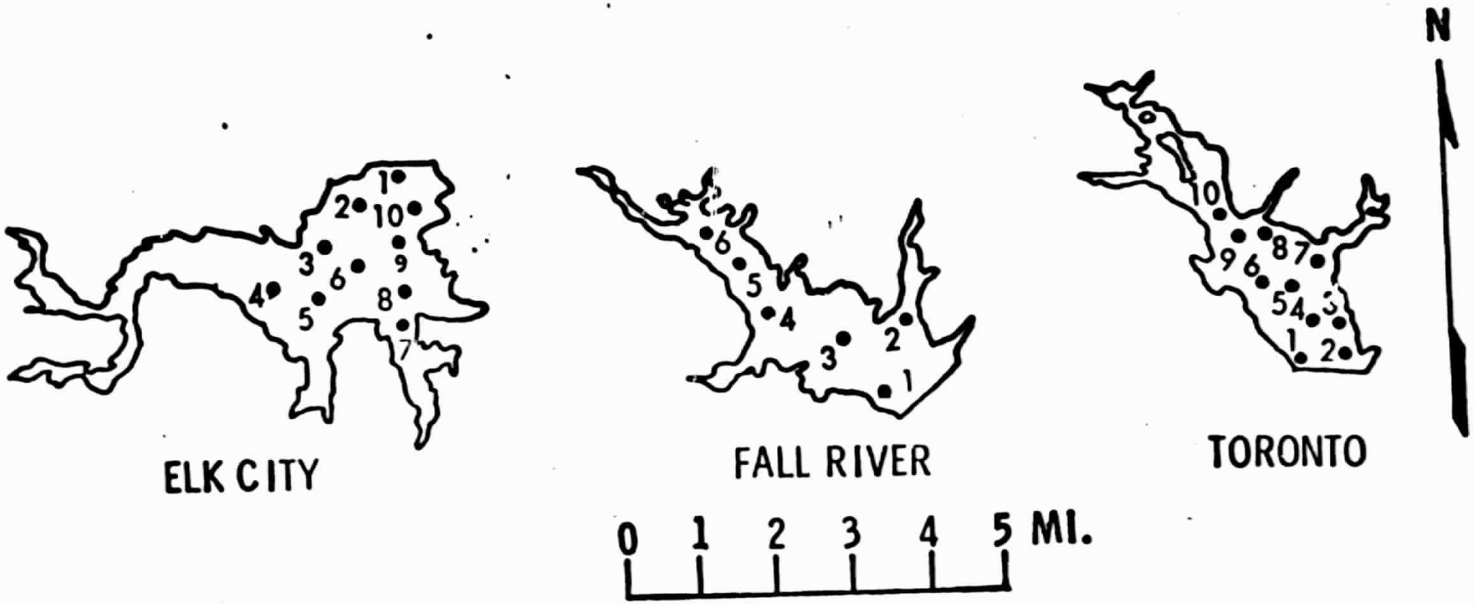

FIGURE 2. WATER SAMPLE STATIONS FOR ELK CITY, FALL RIVER, AND TORONTO RESERVOIRS.

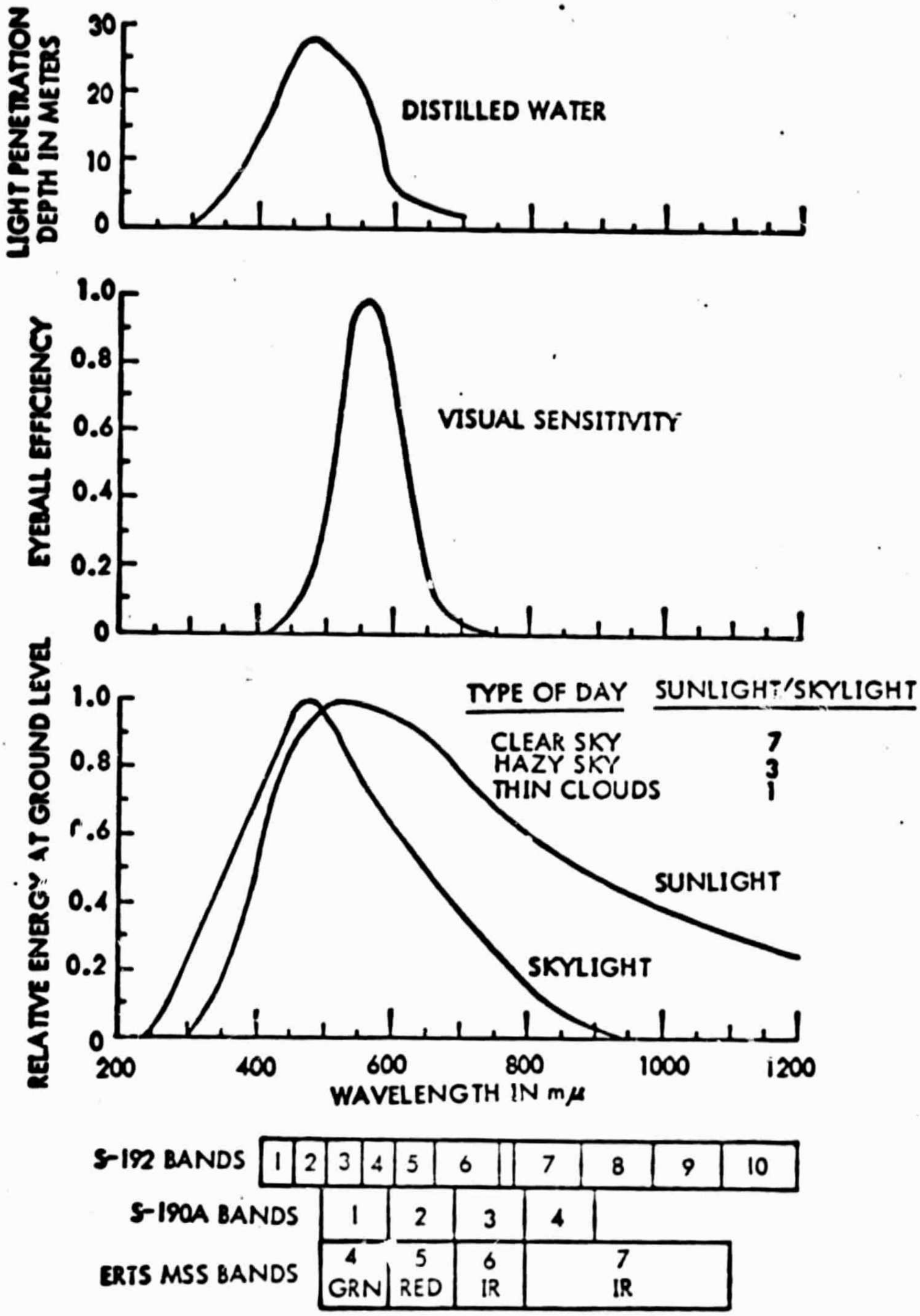

FIGURE 3 RADIANCE vs WAVELENGTH.

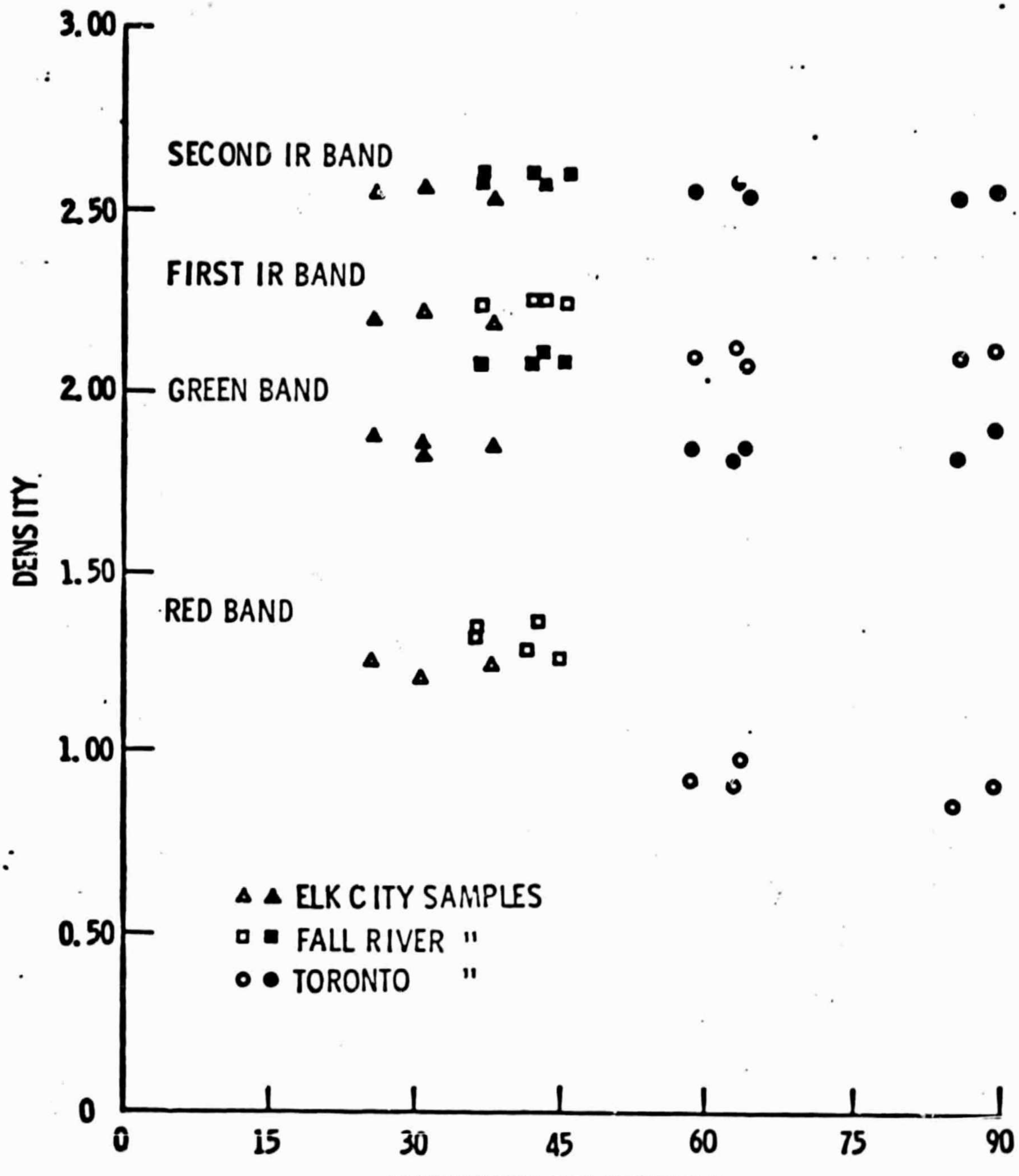

FIGURE 4 S-190A IMAGE DENSITY VS. SUSPENDED SOLIDS FOR WATER SAMPLES TAKEN FROM 3 SOUTHEAST KANSAS RESERVOIRS, SEPT. 18 1973. DENSITIES ARE FROM 4X POSITIVE ENLARGEMENTS OF 70mm. DUPLICATE NEGATIVES.

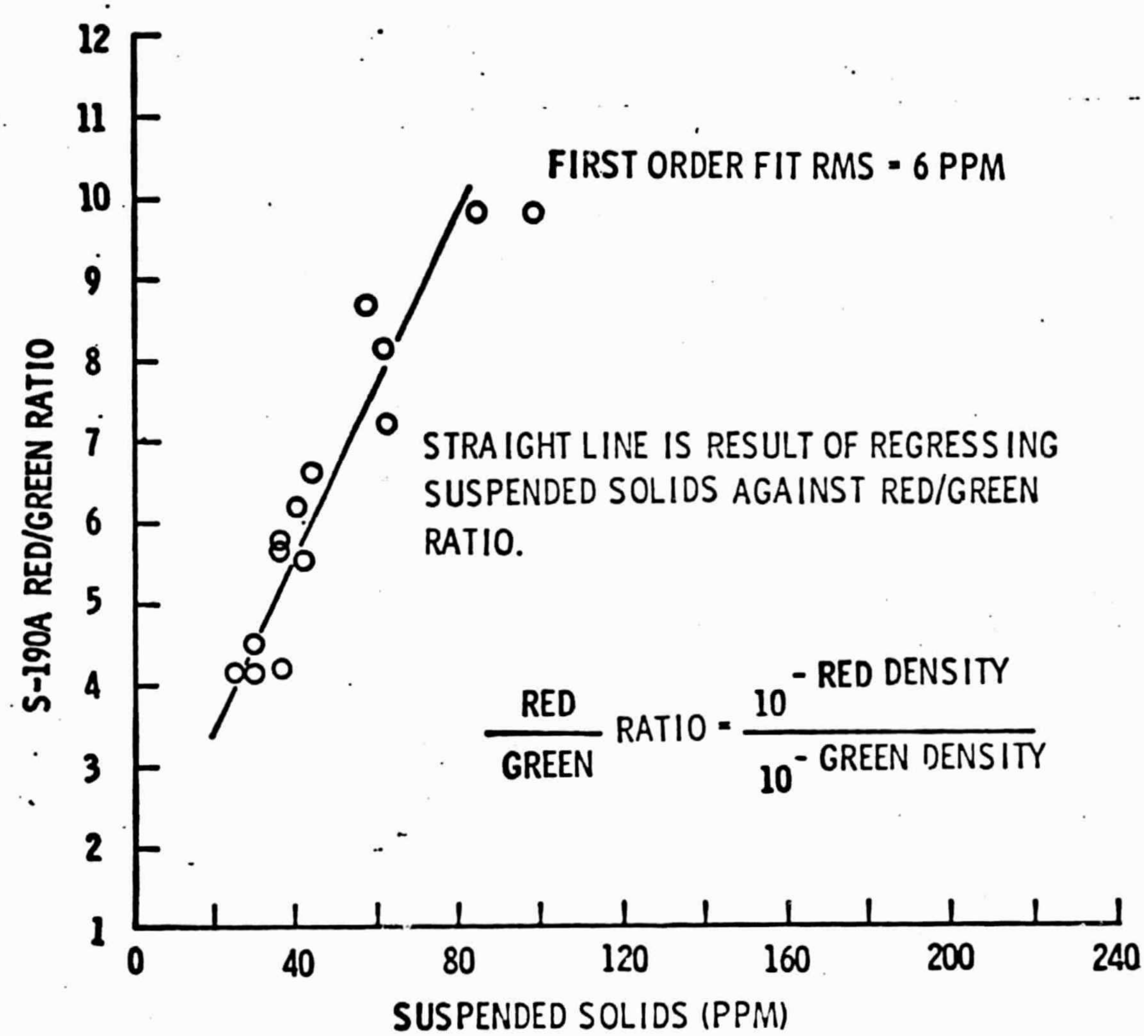

FIGURE 5 RED/ GREEN RATIO VS. SUSPENDED SOLIDS FOR WATER SAMPLES TAKEN FROM 3 S.E. KANSAS RESERVOIRS, SEPT. 18, 1973.

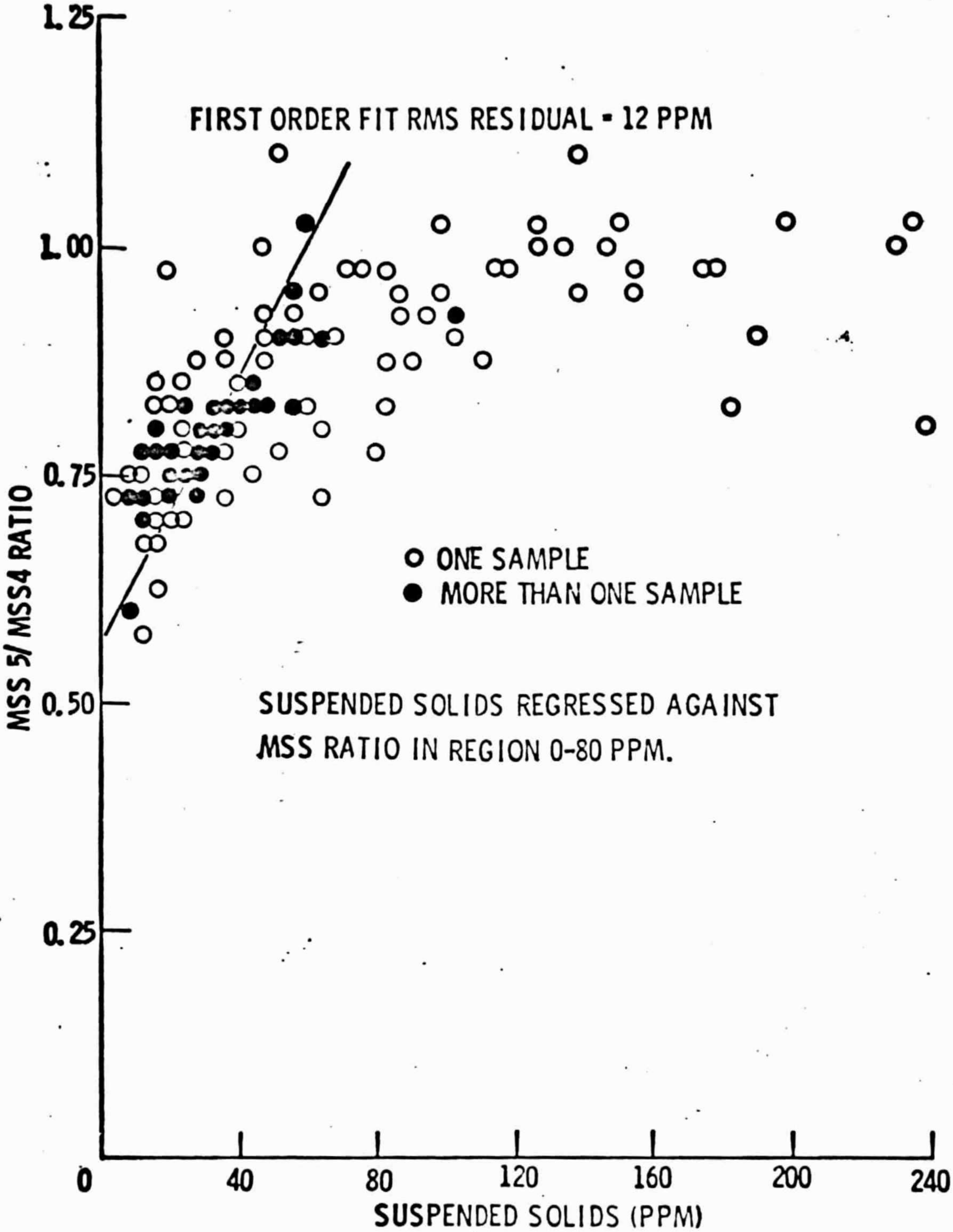

FIGURE 6 MSS 5/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR **167** WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS **DURING** 13 DIFFERENT LANDSAT CYCLES.

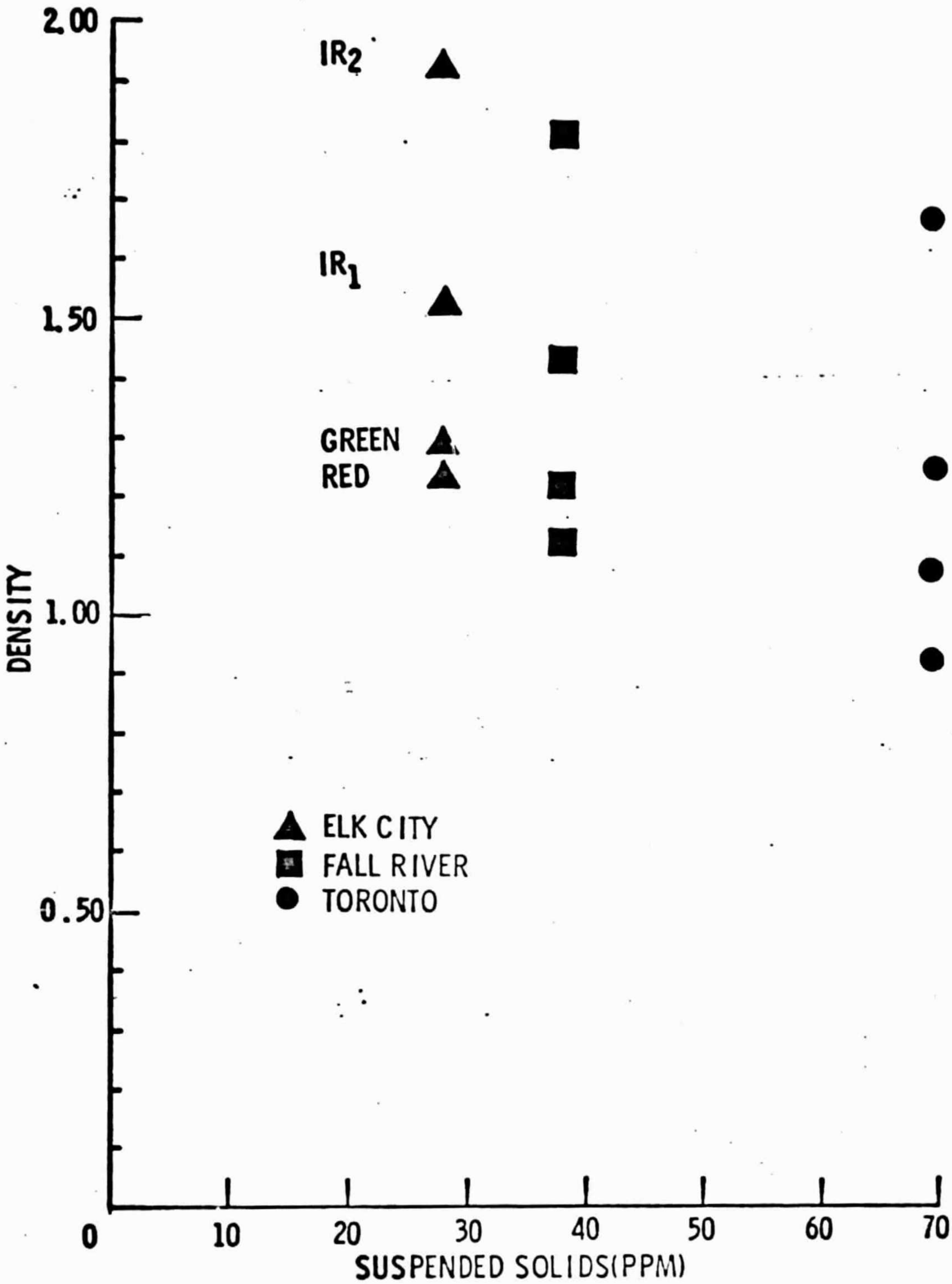

FIGURE 7. S-190A DENSITY VS. SUSPENDED SOLIDS FOR 3 SE KANSAS RESERVOIRS. DENSITY IS FROM SECOND GENERATION 70mm. POSITIVE TRANSPARENCY.

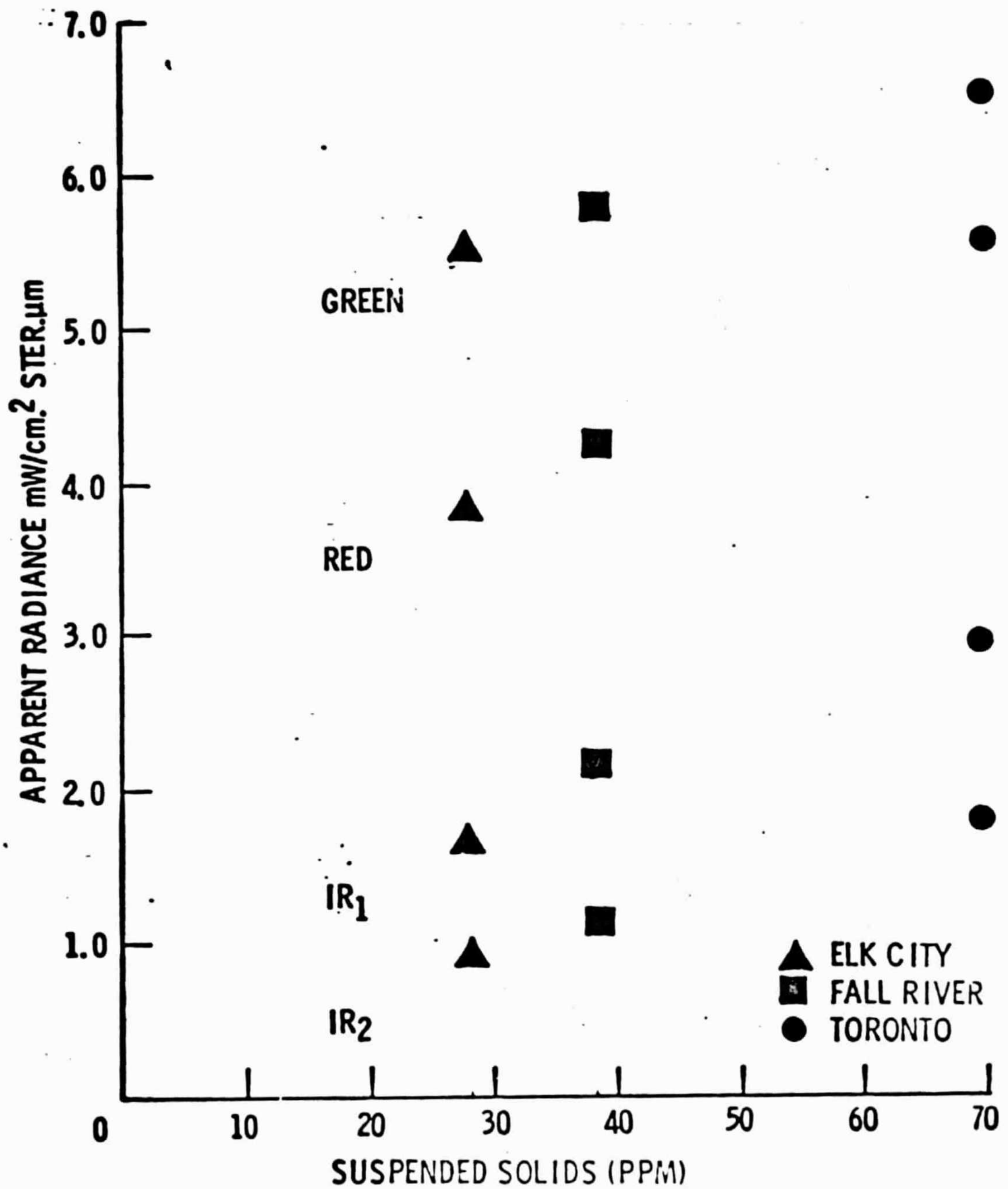

FIGURE 8. S-190A RADIANCE VS. SUSPENDED SOLIDS FOR 3 SE KANSAS RESERVOIRS.

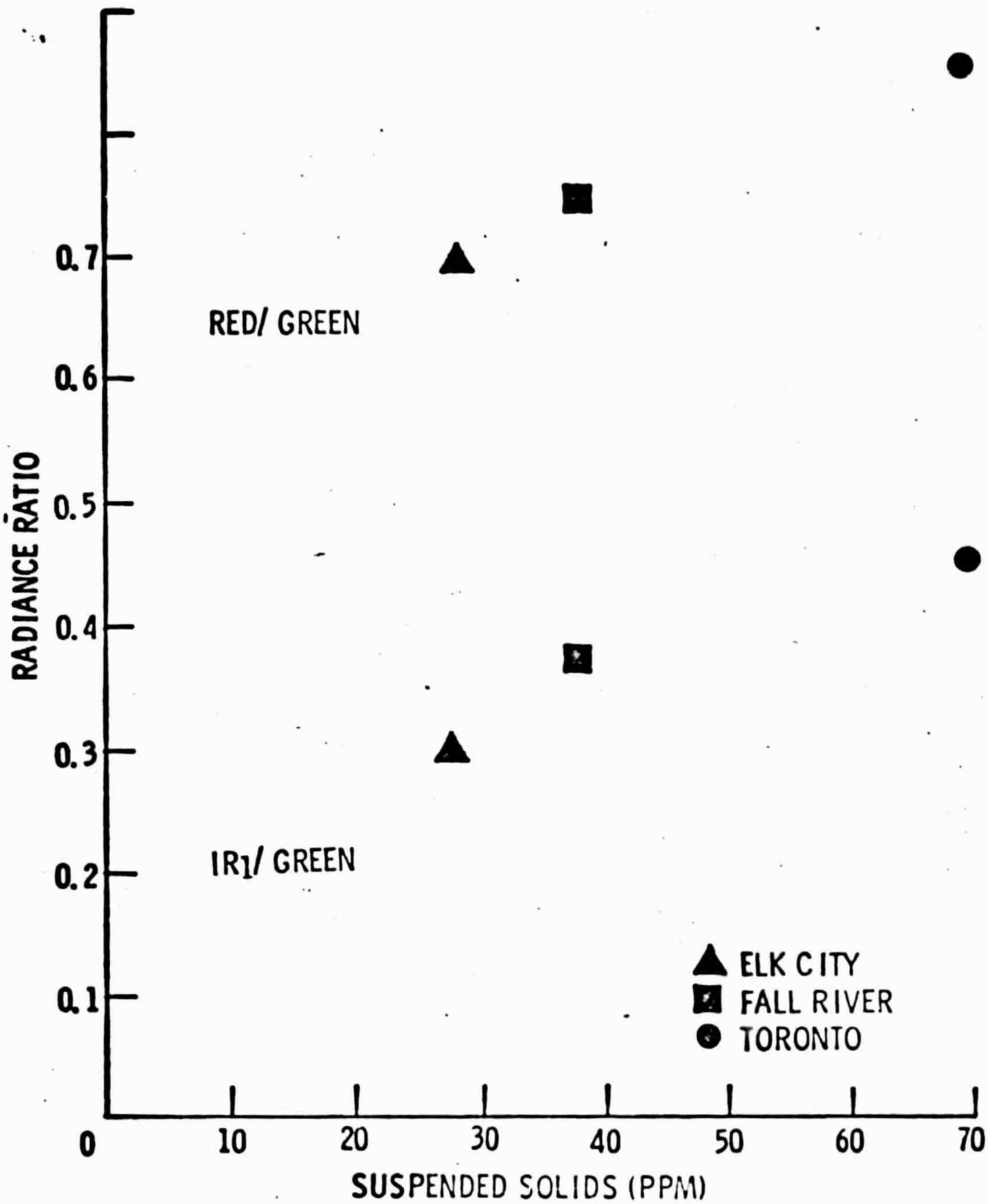

FIGURE 9. S-190A RADIANCE RATIOS VS. SUSPENDED SOLIDS FOR 3 SE KANSAS RESERVOIRS.

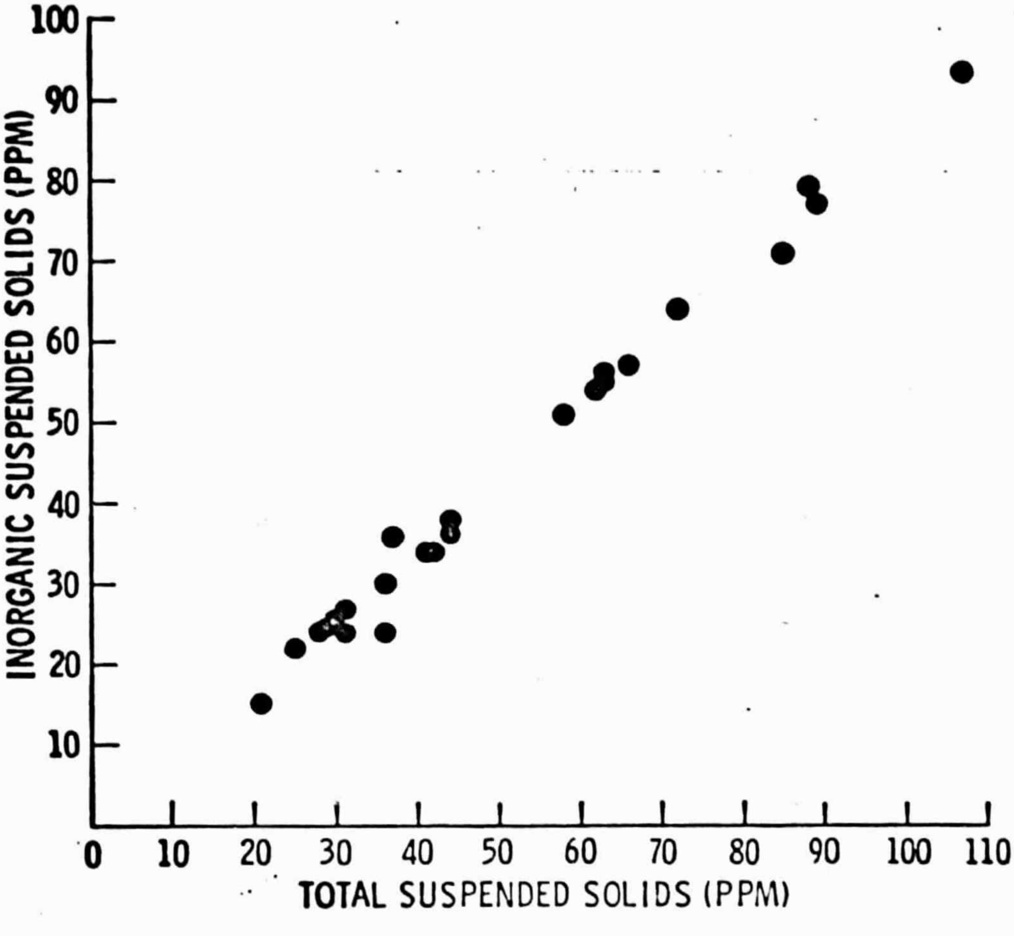

FIGURE 10. INORGANIC SUSPENDED SOLIDS VS. TOTAL SUSPENDED SOLIDS FOR 3 SE KANSAS RESERVOIRS.

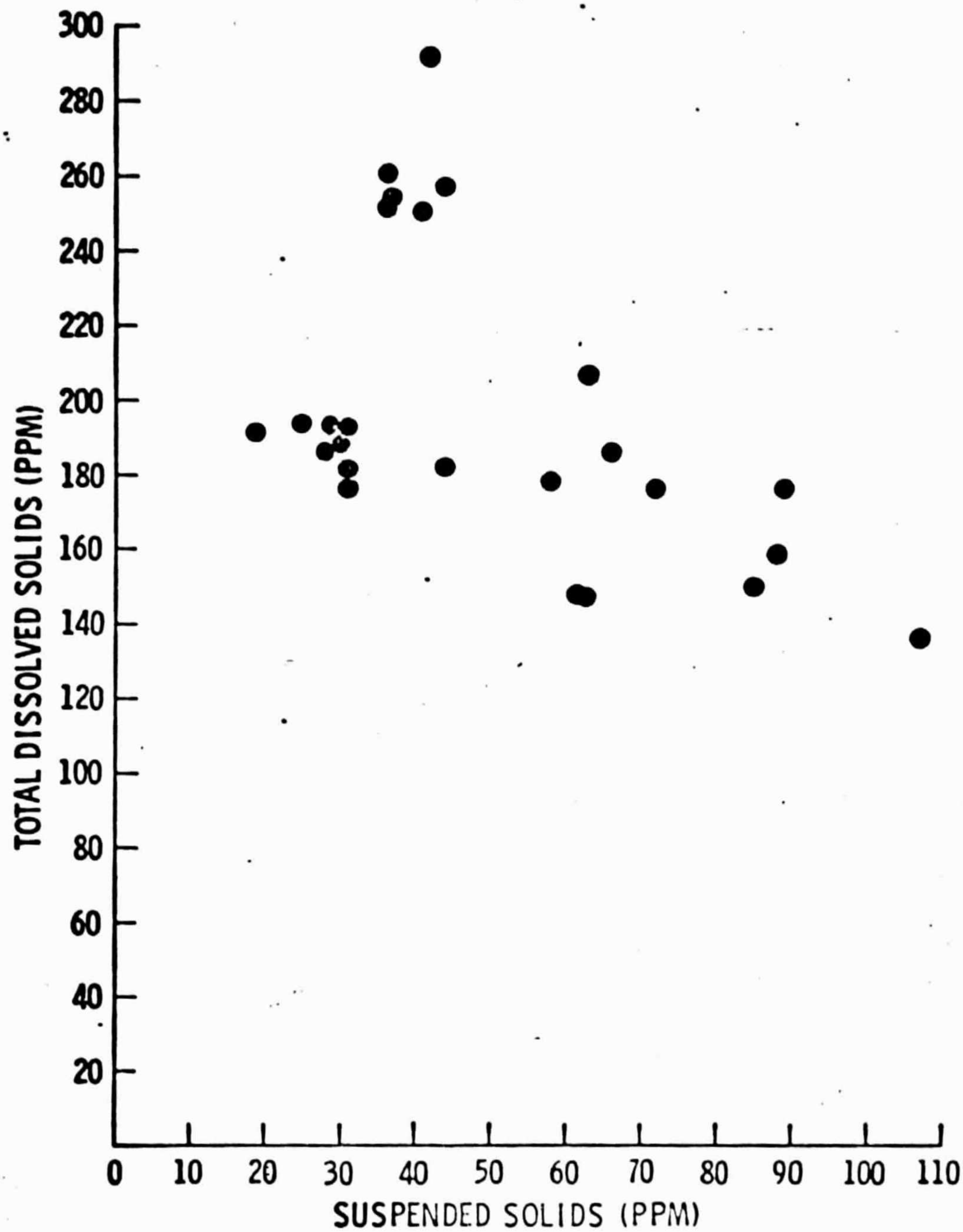

FIGURE 11. TOTAL DISSOLVED SOLIDS VS. SUSPENDED SOLIDS FOR 3 SE KANSAS RESERVOIRS.

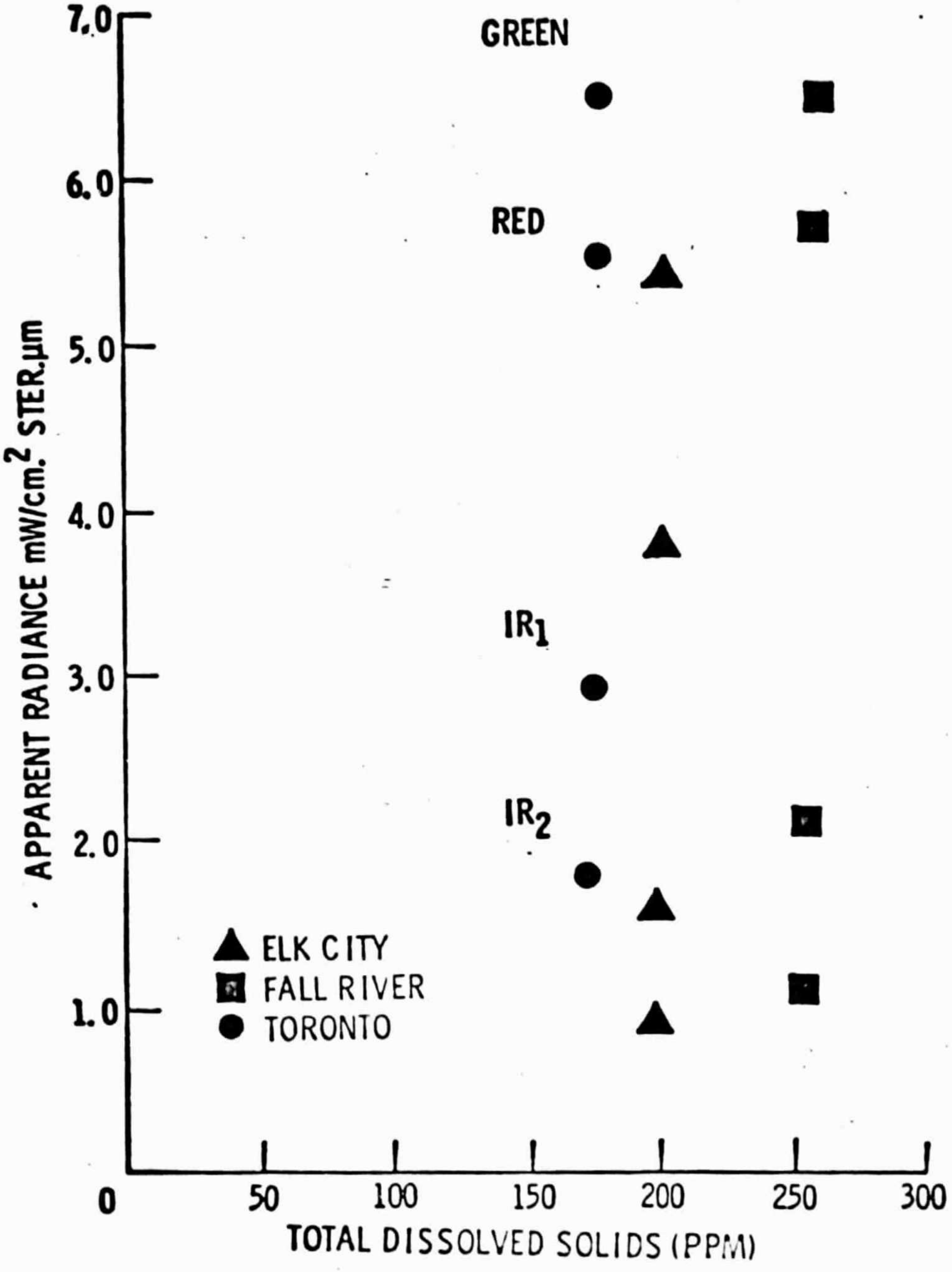

FIGURE 12. S-190A RADIANCE VS. TOTAL DISSOLVED SOLIDS FOR 3 SE KANSAS RESERVOIRS.

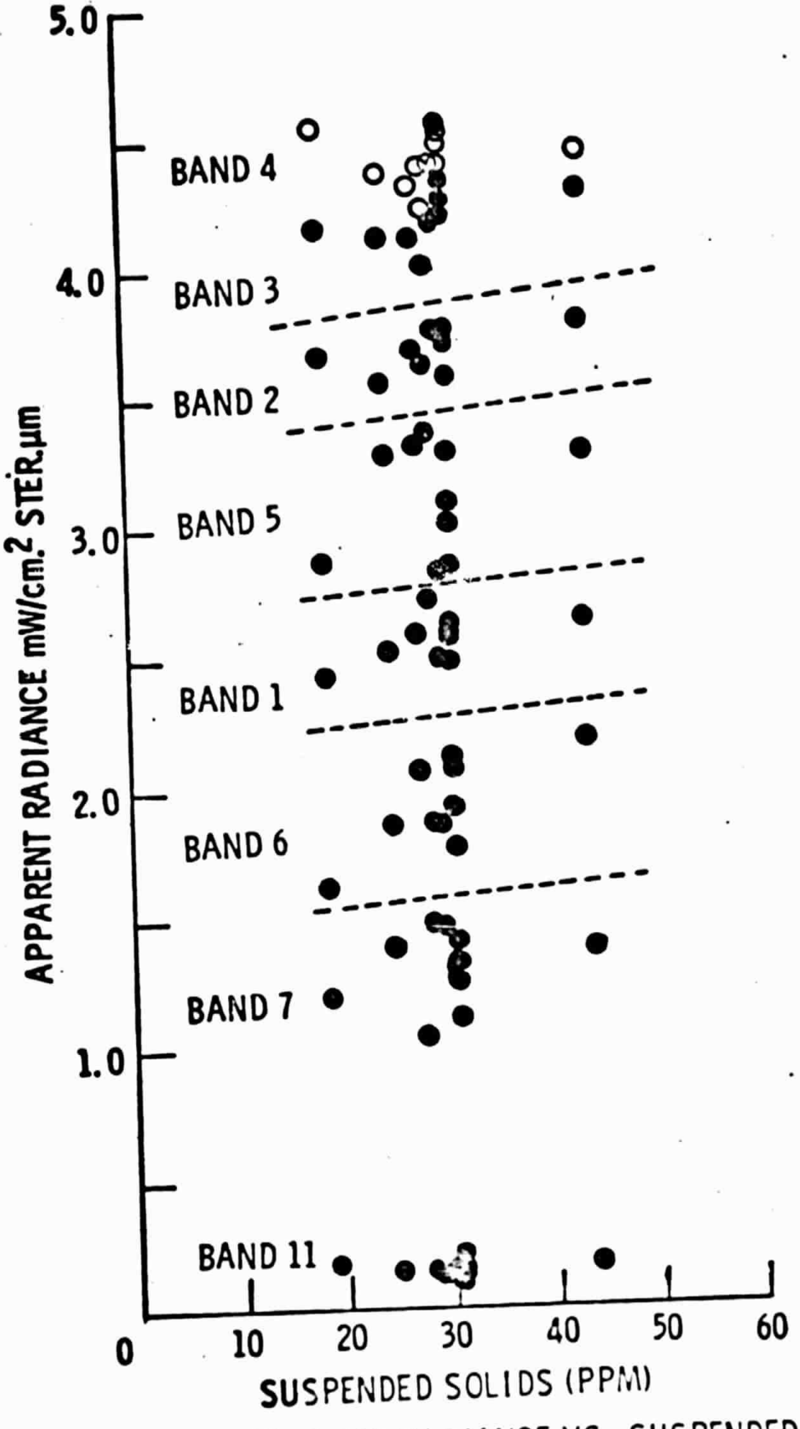

FIGURE 13. S-192 RADIANCE VS. SUSPENDED SOLIDS FOR 3 SE KANSAS RESERVOIRS.

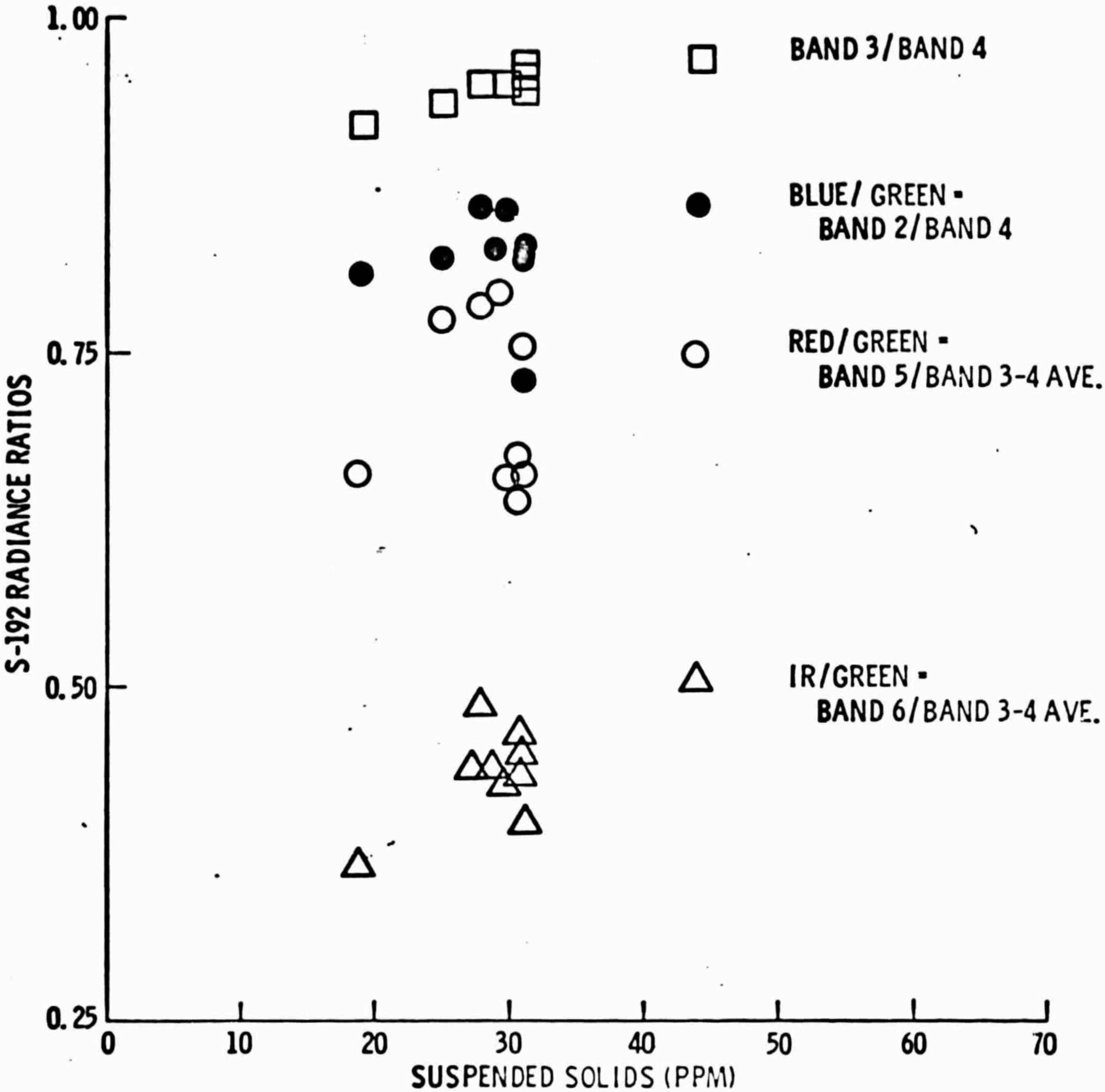

FIGURE 14. S-192 RADIANCE VS. SUSPENDED SOLIDS FOR 3 SE KANSAS RESERVOIRS.

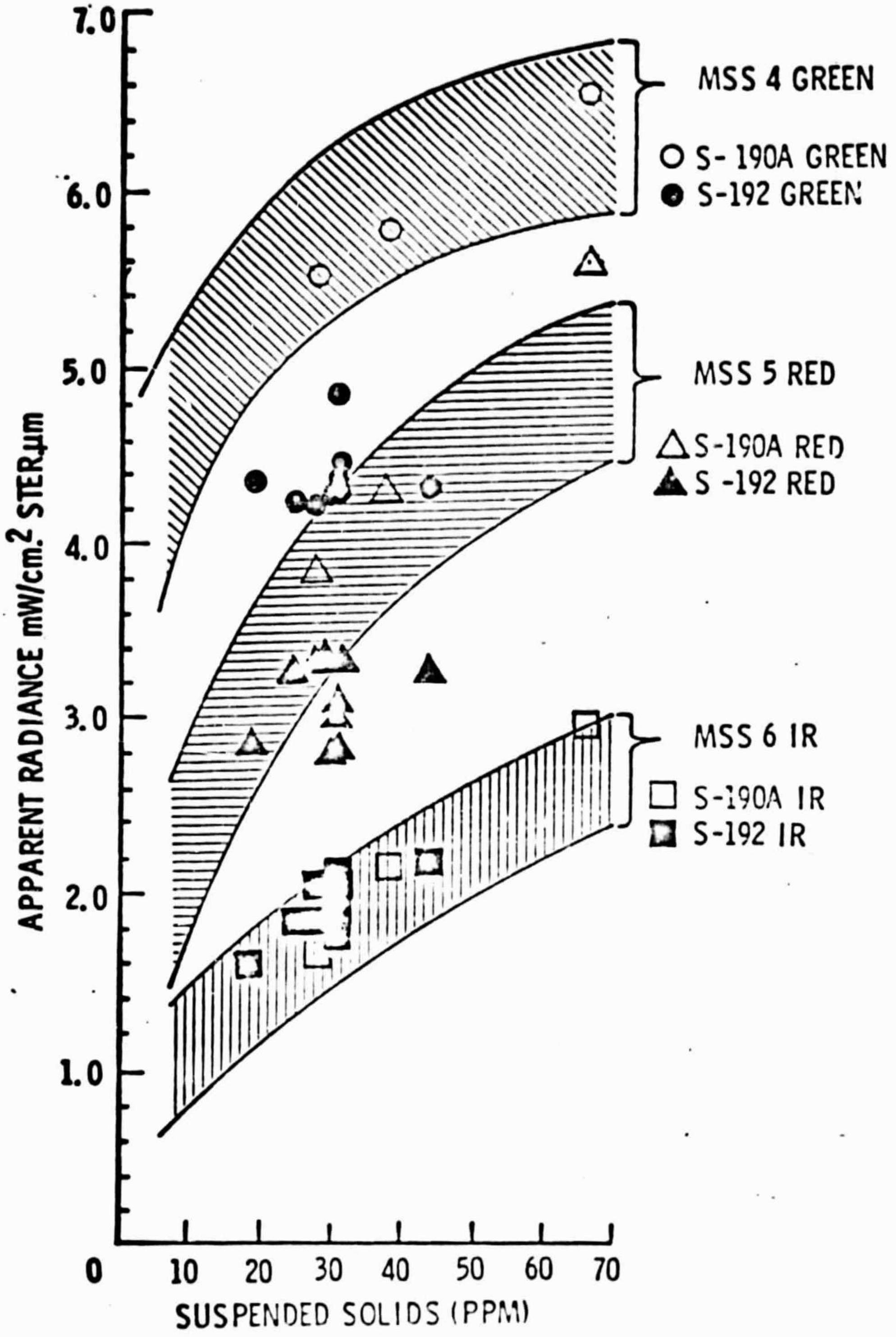

FIGURE 15. RADIANCE VS. SUSPENDED SOLIDS. ONE SL-3 PASS (SUN ANGLE = 44°) OVER 3 S.E. KANSAS RESERVOIRS AND 7 LANDSAT PASSES (SUN ANGLE = 40°- 54°) OVER 3 N.E. KANSAS RESERVOIRS.

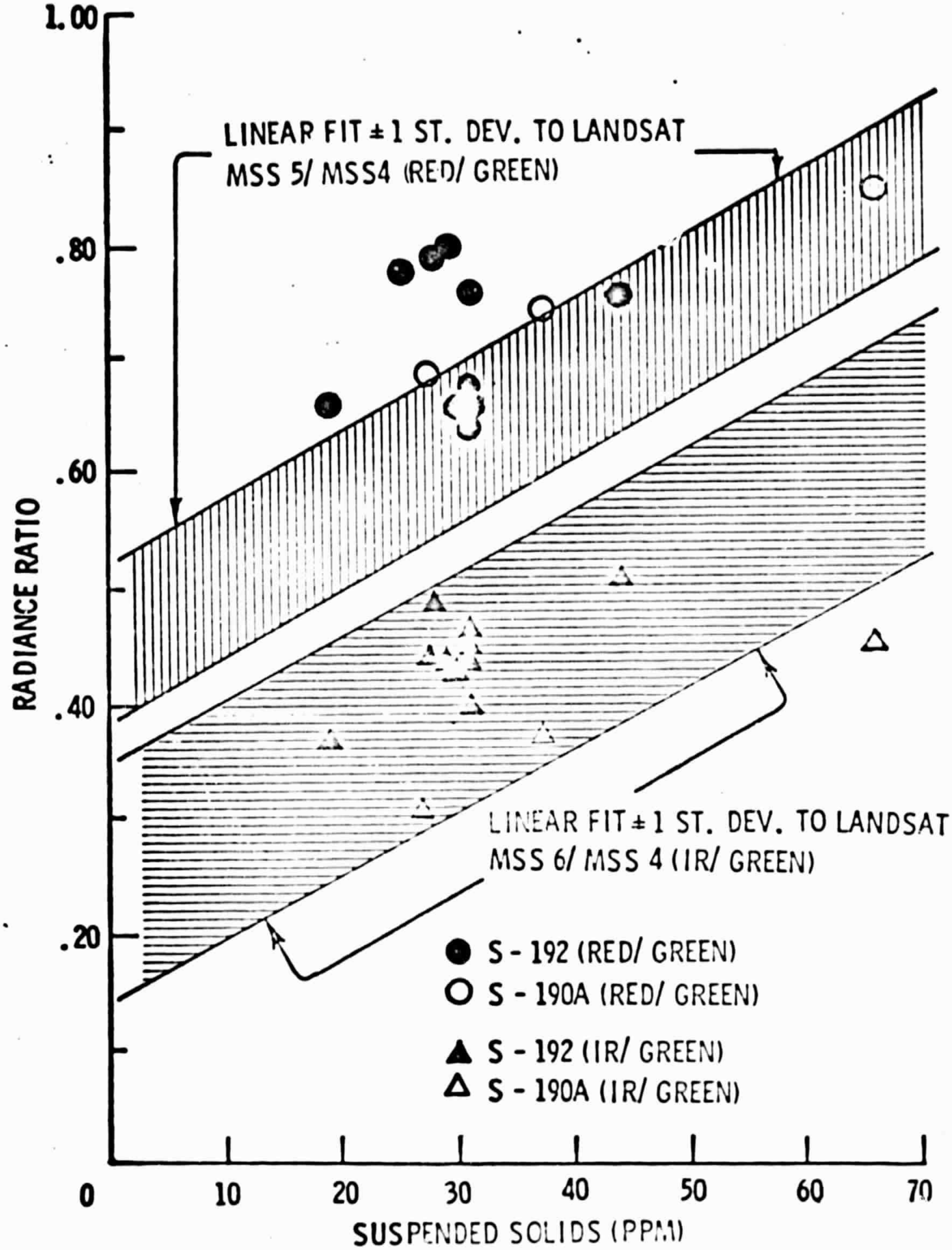

FIGURE 16. RADIANCE RATIOS VS. SUSPENDED SOLIDS. ONE SL-3 PASS (9/13/73) OVER 3 S.E. KANSAS RESERVOIRS & 13 LANDSAT CYCLES OVER 3 RESERVOIRS IN N.E. KANSAS OVER THE PERIOD JULY 25, 1972 TO AUG. 27, 1973.